EUV and Beyond EUV optics research at the University of Twente

November 11, 2015

Eric Louis, Robbert van de Kruijs, Andrey Yakshin, Johan Reinink, Dmitry Kuznetsov, Ben Wylie van Eerd, Chris Lee and Fred Bijkerk,
Hartmut Enkisch* and Stephan Müllender*

* Carl Zeiss SMT GmbH

University of Twente / MESA+

Multilayer R & D program

University of Twente

MESA+ Institute for Nanotechnology

XUV OPTICS

Focus Group in Twente

From 1st July 2014

Formerly FOM DIFFER/Rijnhuizen

provincie Overijssel

SolMateS

TNO

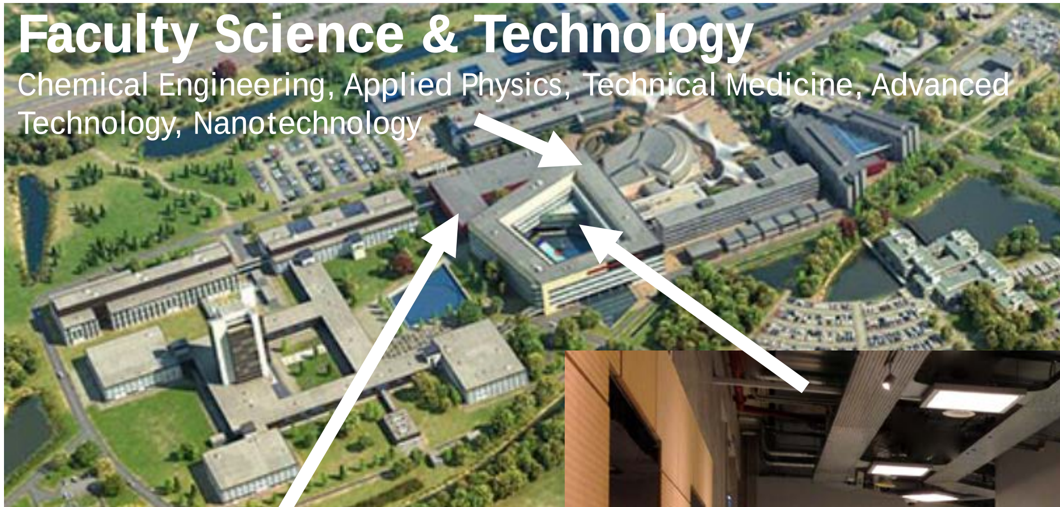
DEMCON

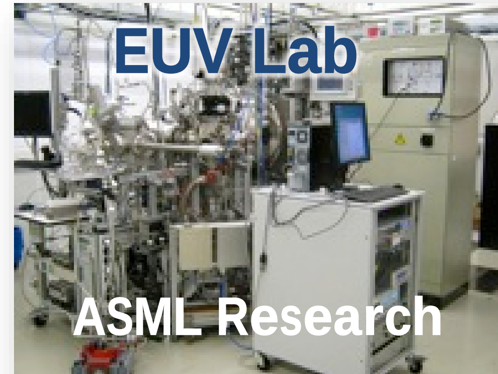
XUV

FOM PANalytical ASML ZEISS MESA+ UNIVERSITY OF TWENTE.

XUV Optics MESA+ & EUV lab ASML

MESA+ Institute for Nanotechnology





NanoLab

1250 m² cleanroom
materials analysis laboratory
chemical synthesis and analysis,
materials research, lithography

XUV Optics Lab

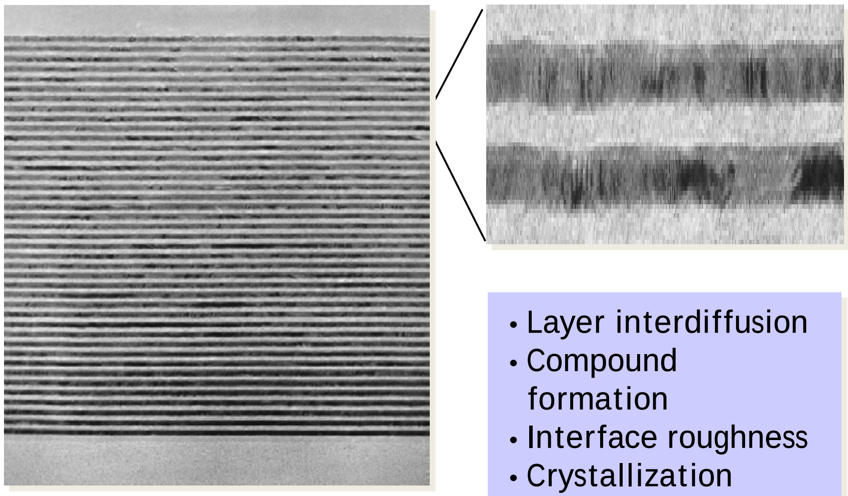
500 m² Thin film & multilayer facilities
Physical/chemical synthesis and analysis, advanced deposition set-ups

Outline

- ✓ Mo/Si multilayer, reflectance and stability
- ✓ Recent developments:
  - Stress in multilayers
  - 6.x nm multilayers
  - EUV adaptive optics

Interface engineering

HRTEM

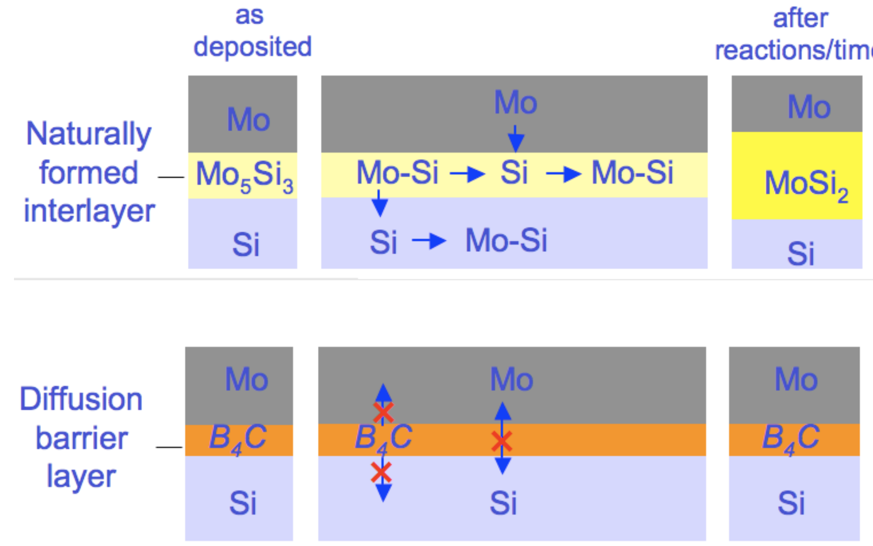


50 periods Mo/Si

d = 6.9 nm, $\Gamma \approx 0.4$

Dr. F. Tichelaar, Delft University of Technology

- Layer interdiffusion
- Compound formation
- Interface roughness
- Crystallization
- Density variations
- Void formations...



→ *Diffusion barrier layers reqd at sub-nm thickness*

→ *Materials & growth determined*

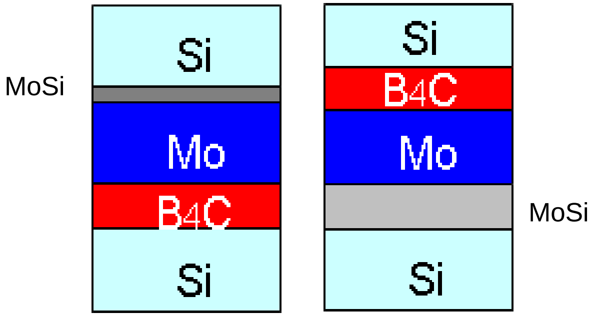
→ ***'Interface engineering'***

Thin barriers: prevent diffusion & enhance reflectance

Thick barriers: prevent diffusion

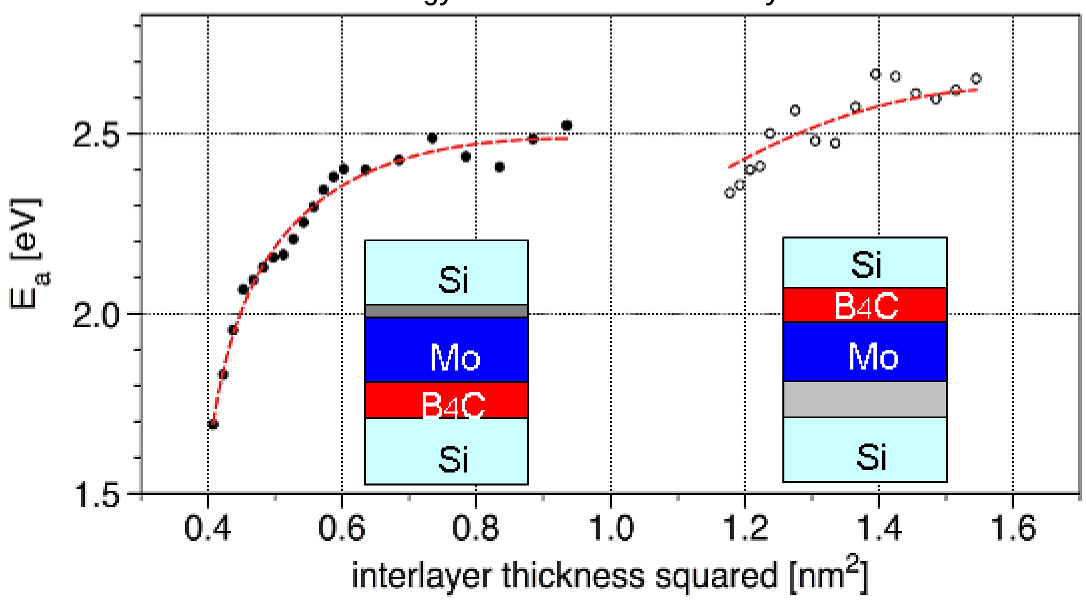
XUV FOM PANalytical ASML ZEISS MESA+ INSTITUTE FOR NANOTECHNOLOGY UNIVERSITY OF TWENTE.

Untangling the interfaces



- block diffusion through one interface, study the other one

Activation energy as function of interlayer thickness

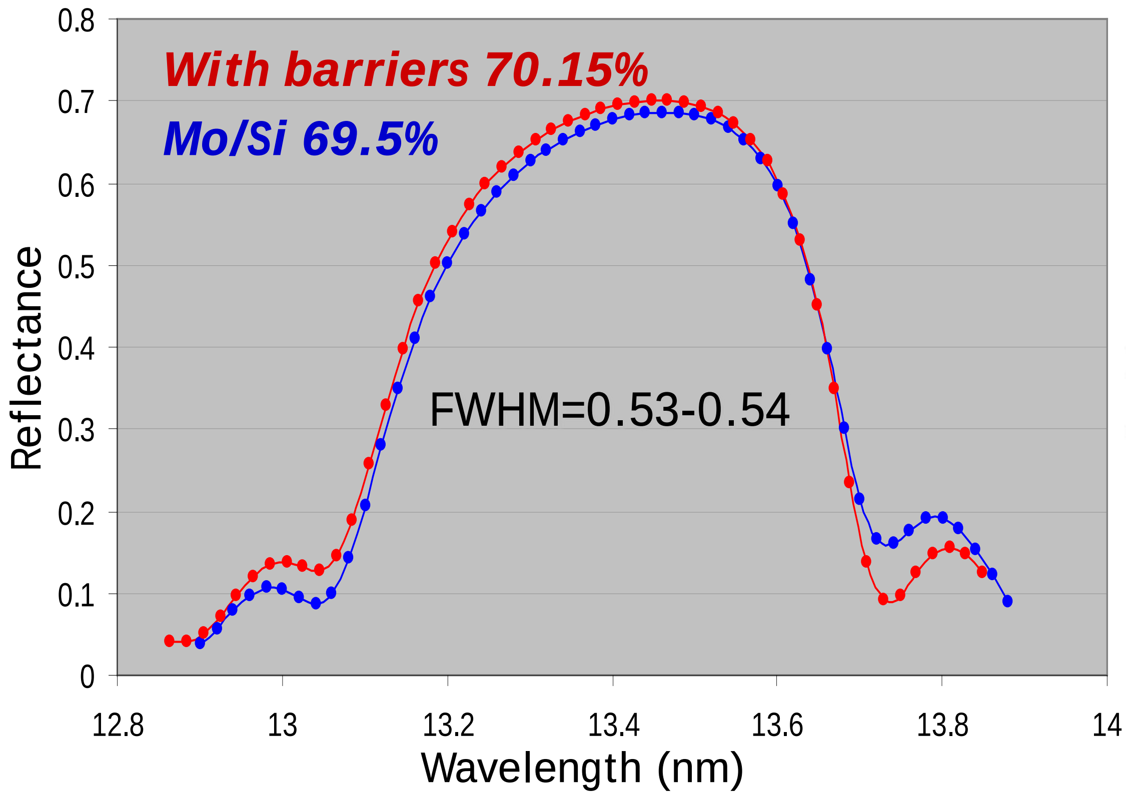


E_a increases with increased interface growth, compaction slows down

Bosgra et al., Thin Solid Films 522 (2012), 228

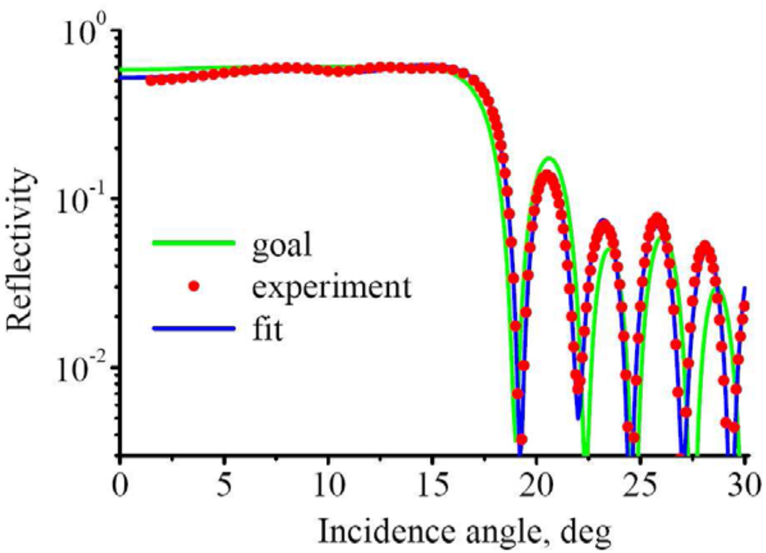
Thin barriers: reflectance & bandwidth

Reflectance @ 1.5 º off-normal



A.E. Yakshin, R.W.E. van de Kruijs, et al, SPIE, Vol. 6517, 2007

Improved angular width: depth graded ML

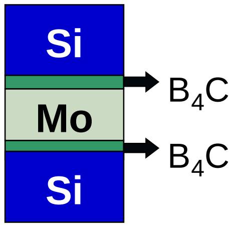


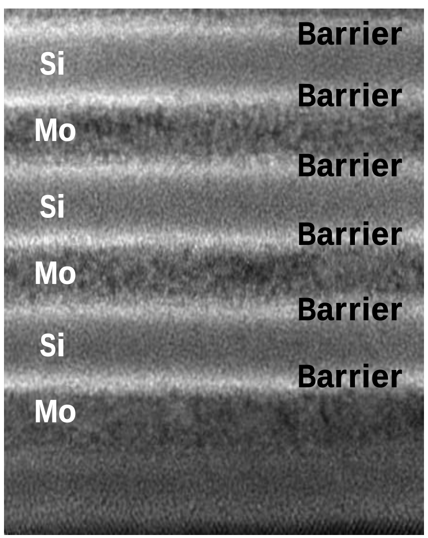
A.E. Yakshin et al, Optics Express **18**, 6957-6971 (2010)

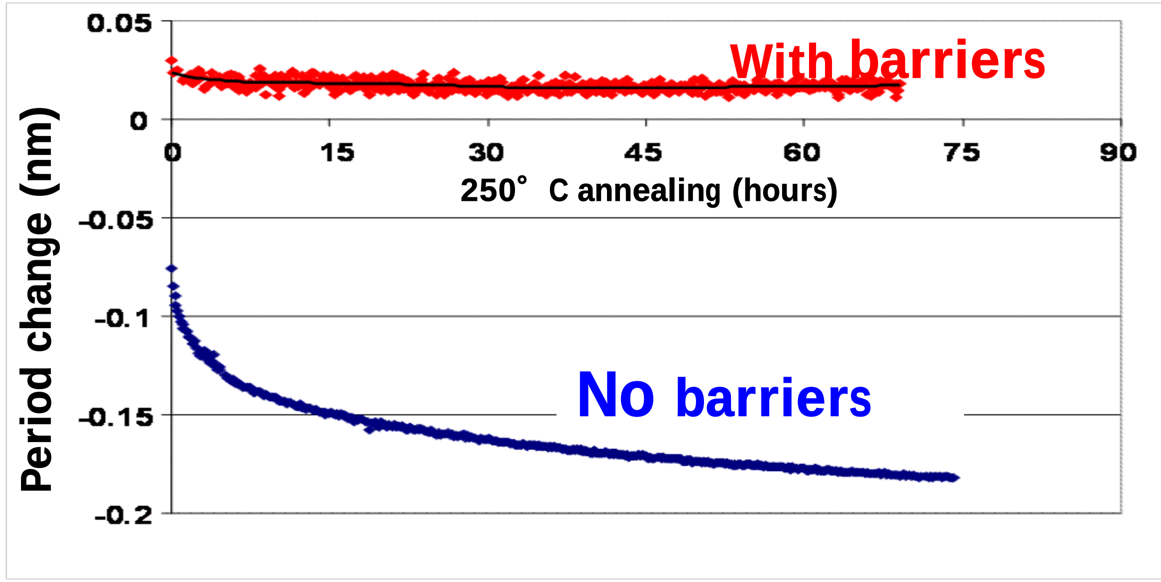
Thin barriers enable reflectance enhancement !

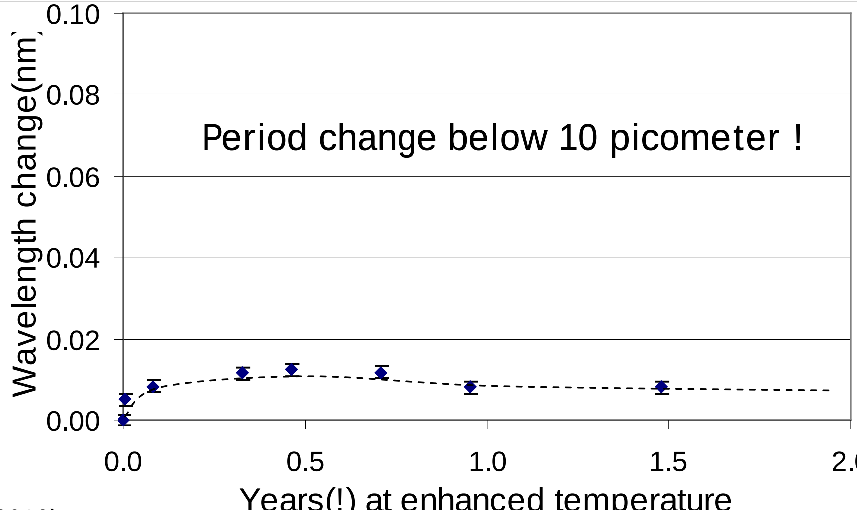
XUV FOM PANalytical ASML ZEISS MESA+ INSTITUTE FOR NANOTECHNOLOGY UNIVERSITY OF TWENTE.

Stable multilayer





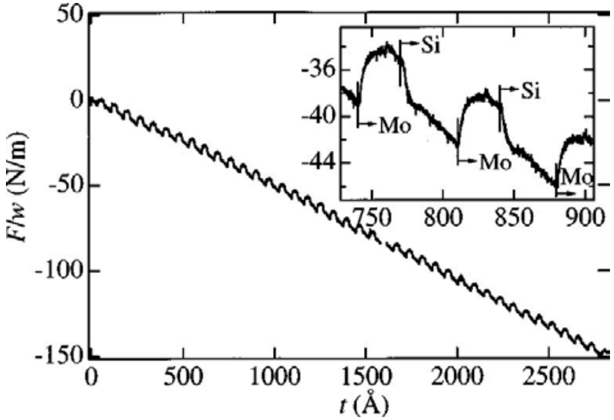




Nyabero et al., Applied Physics Letters 103, 093105 (2013)

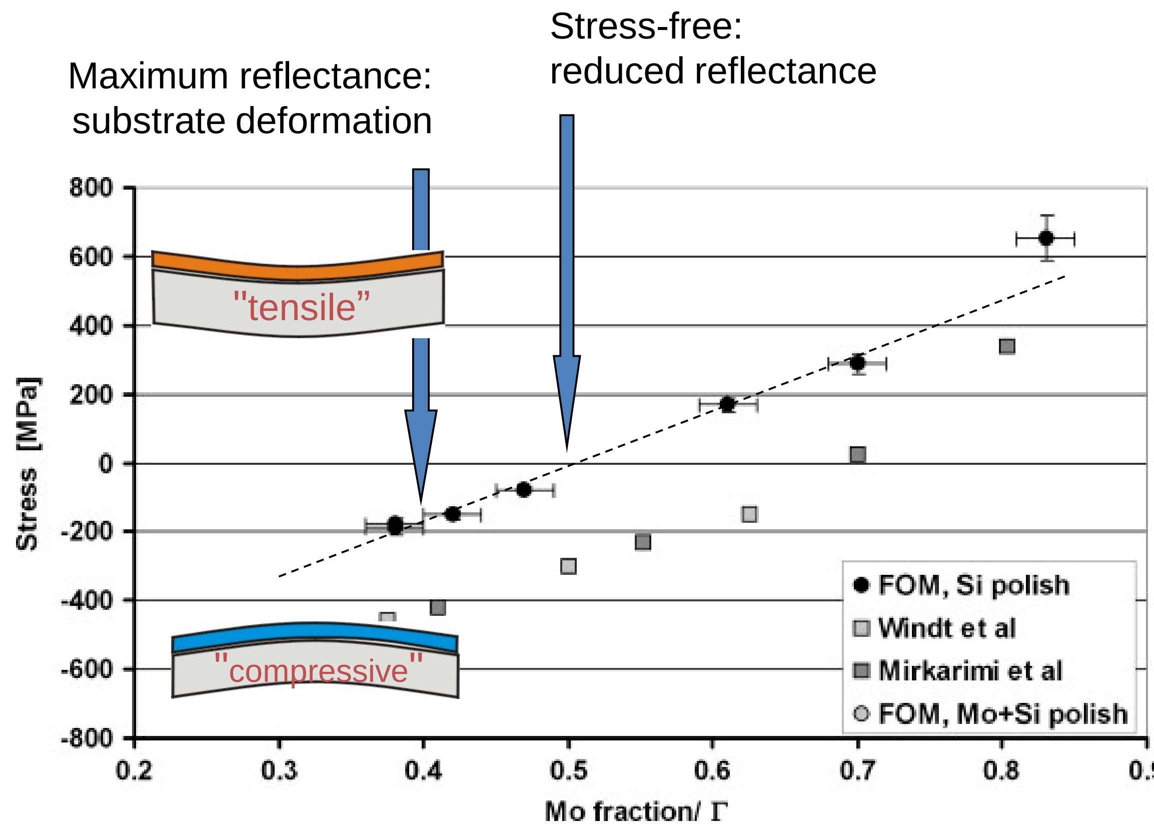
XUV FOM PANalytical ASML ZEISS MESA+ INSTITUTE FOR NANOTECHNOLOGY UNIVERSITY OF TWENTE.

Multilayer induced stress



J.M.Freitag et al:
APL vol. 73(1) 1998

Single beam laser deflection set up



Stress behavior confirmed by WAXD

Louis et al., Progress in Surface Science 86 (11-12) (2011) 255-294

- Substrate deformation *unacceptable!* Reflectance loss *unacceptable!*

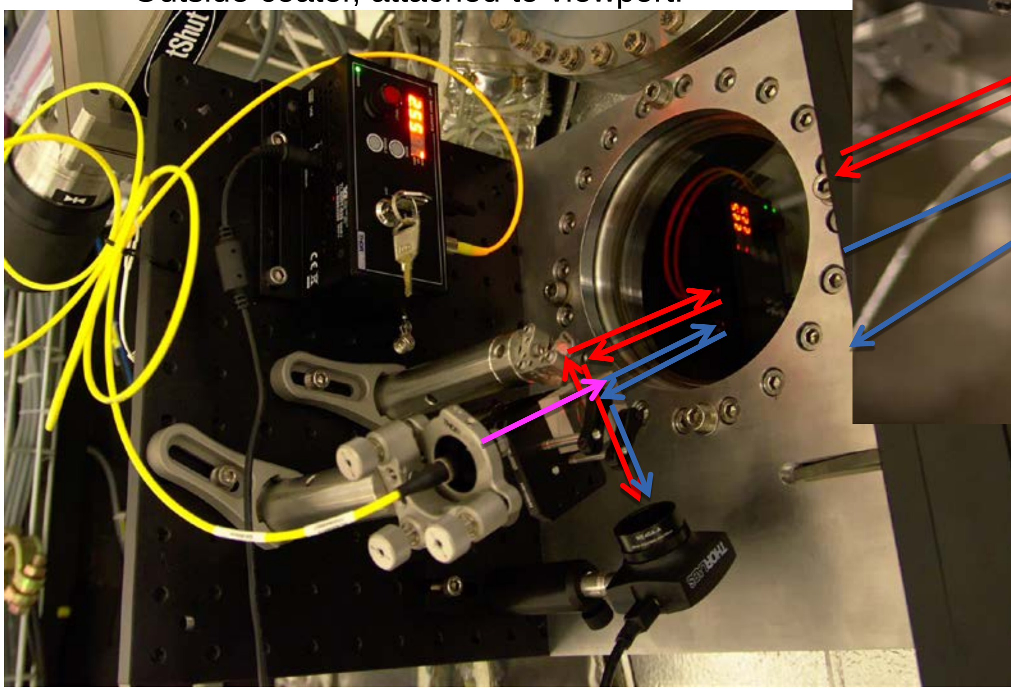
In-situ stress measurement tool

Stress development mechanisms of deposition parameters and interface engineering

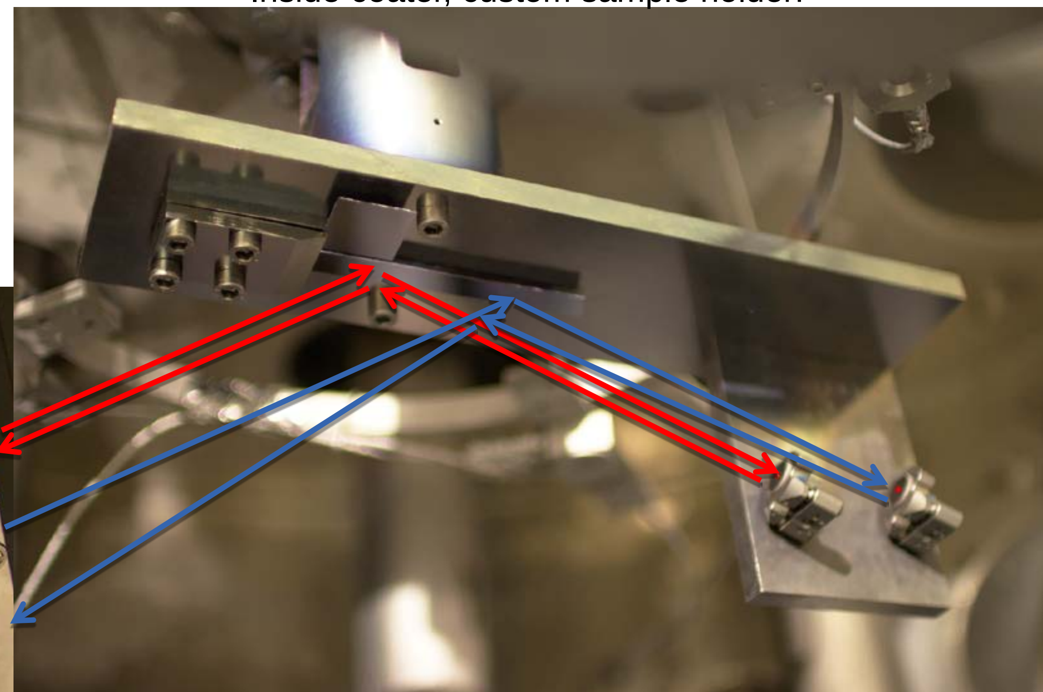
Dual beam laser deflectometer

in-situ stress measurement

Outside coater, attached to viewport:



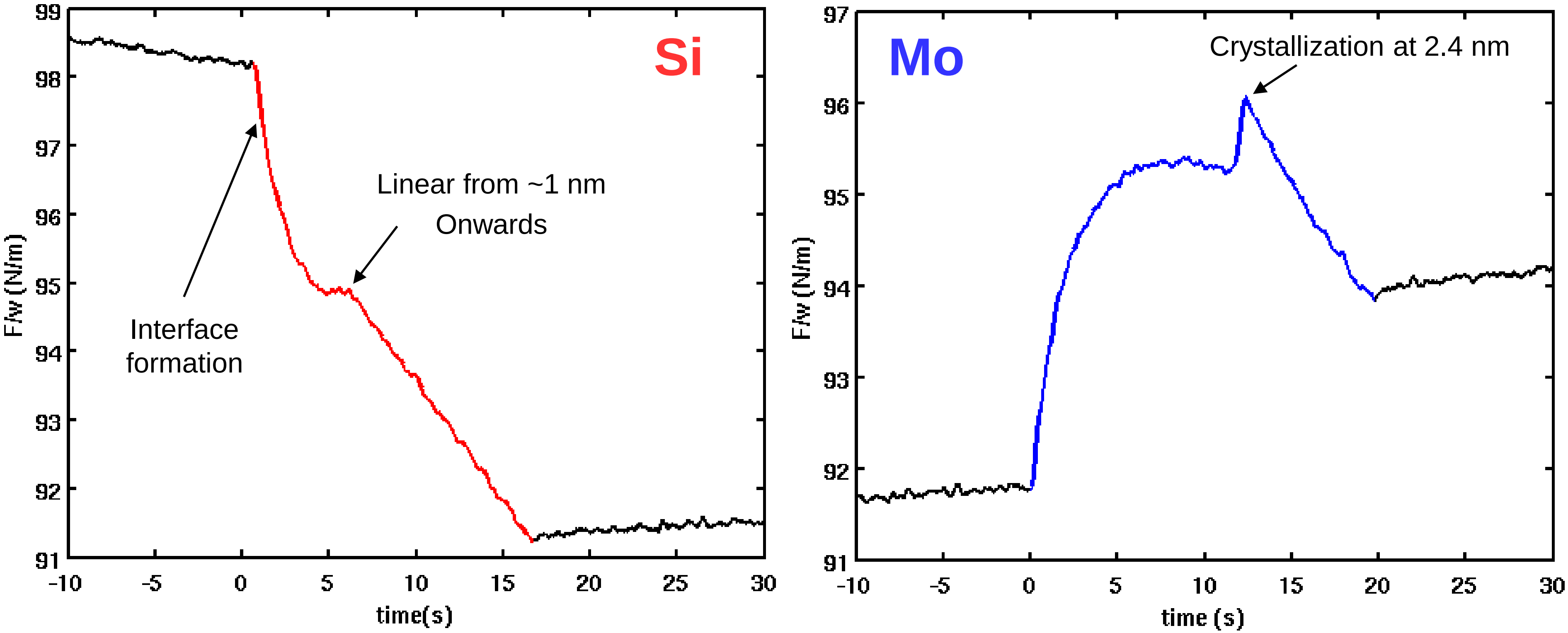
Inside coater, custom sample holder:



High resolution

in-situ stress measurement

Mo/Si multilayer

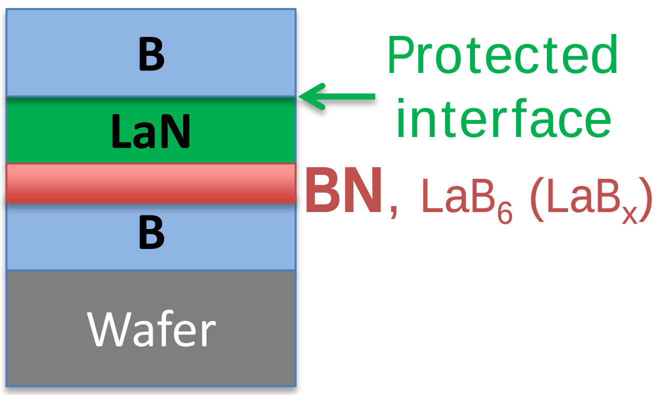


→ Interlayer formation induced stress

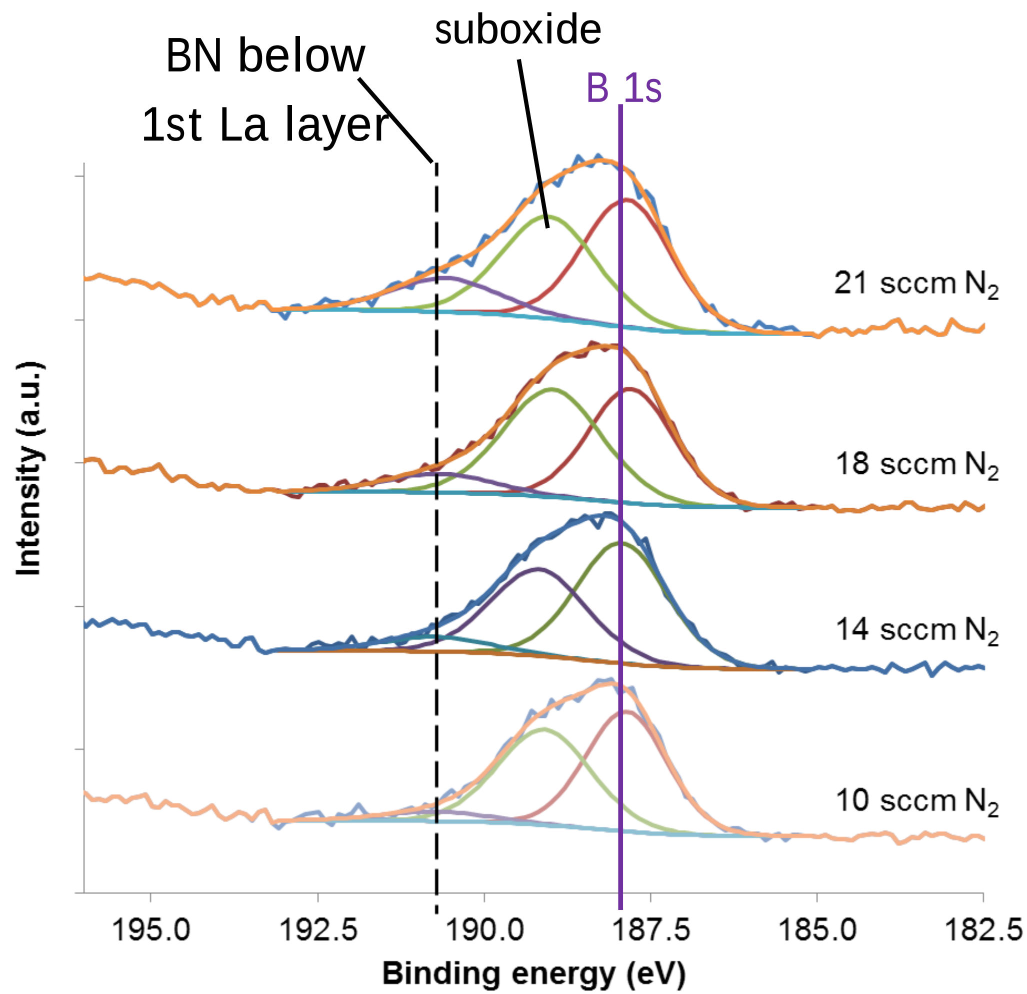
Effect of crystallization of Mo on stress

Multilayers for 6.x nm: LaN/B

Initial system: LaN/B

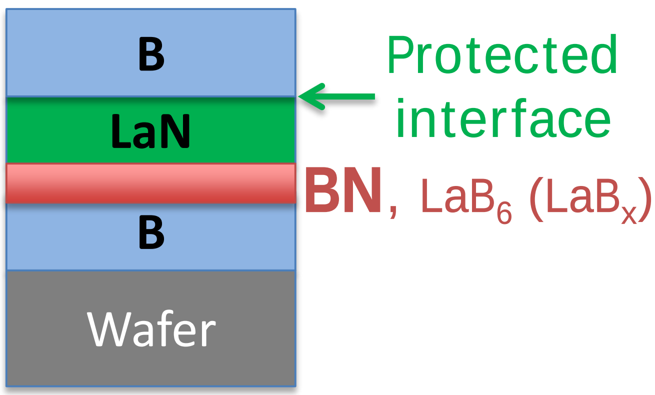


→ AR-XPS: BN formed below LaN layer

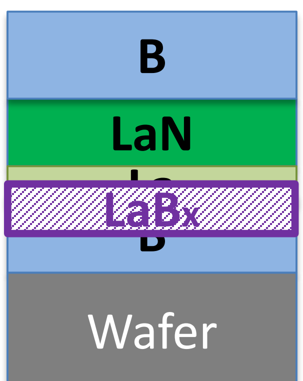


LaN/B and delayed nitridation

Initial system: LaN/B

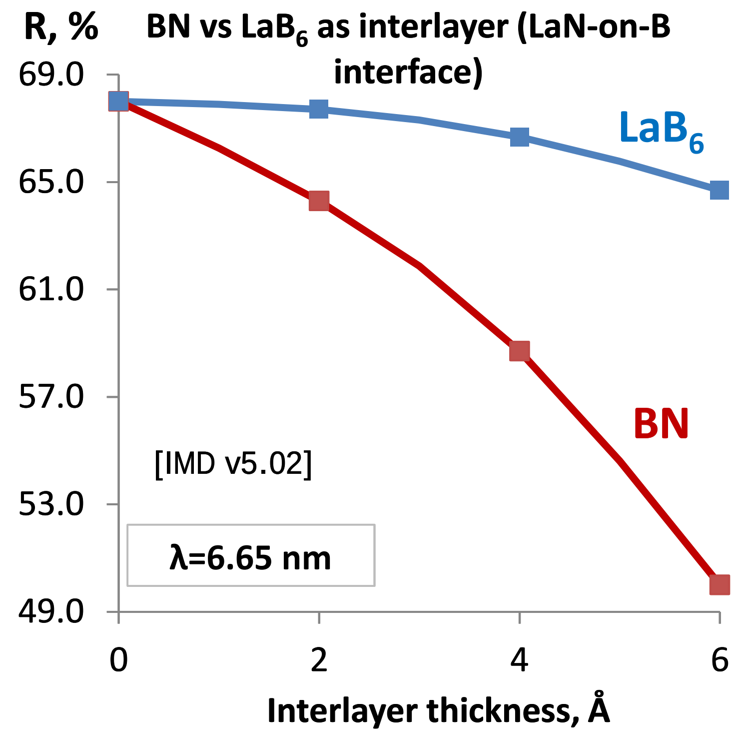


New system: LaN/La/B



Step 2: fully-passivated LaN

Step 1: non passivated La



Formation of LaB_6 (LaB_x) very favorable ($\Delta H(LaB_6) \approx$ - 130 kJ/mol*), proven** for La/B

[A. I. Efimov Handbook, Khimiya, Leningrad, 1983]

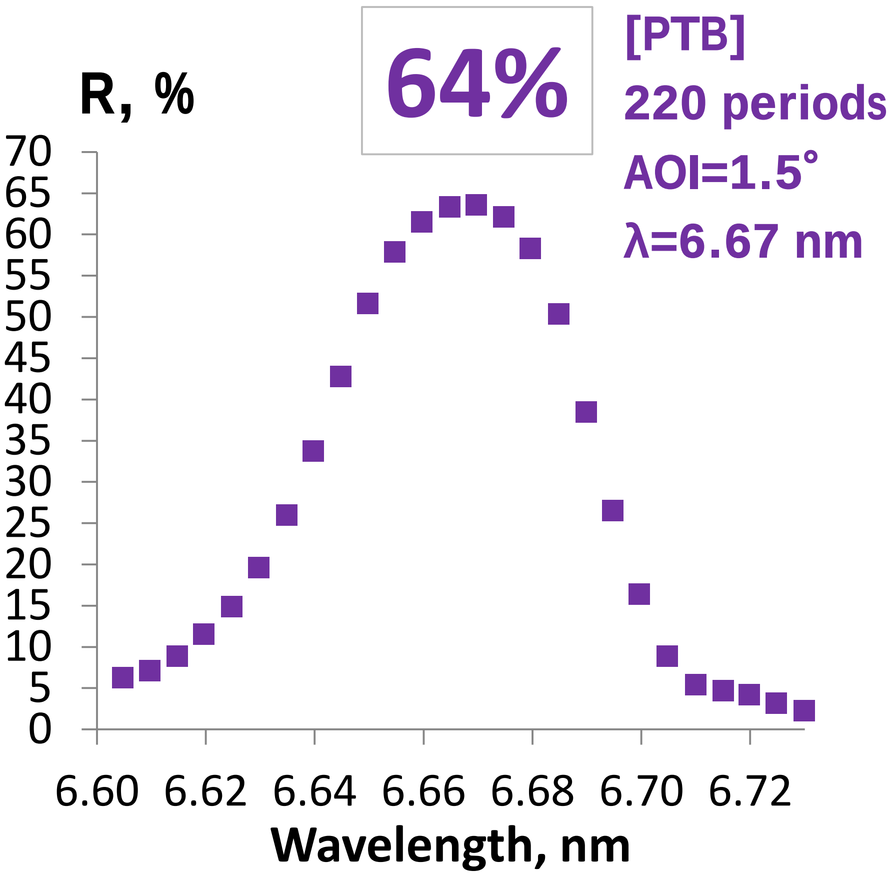
***[I. A. Makhotkin et al., Optics Express 20(11), 11778 (2012)]*

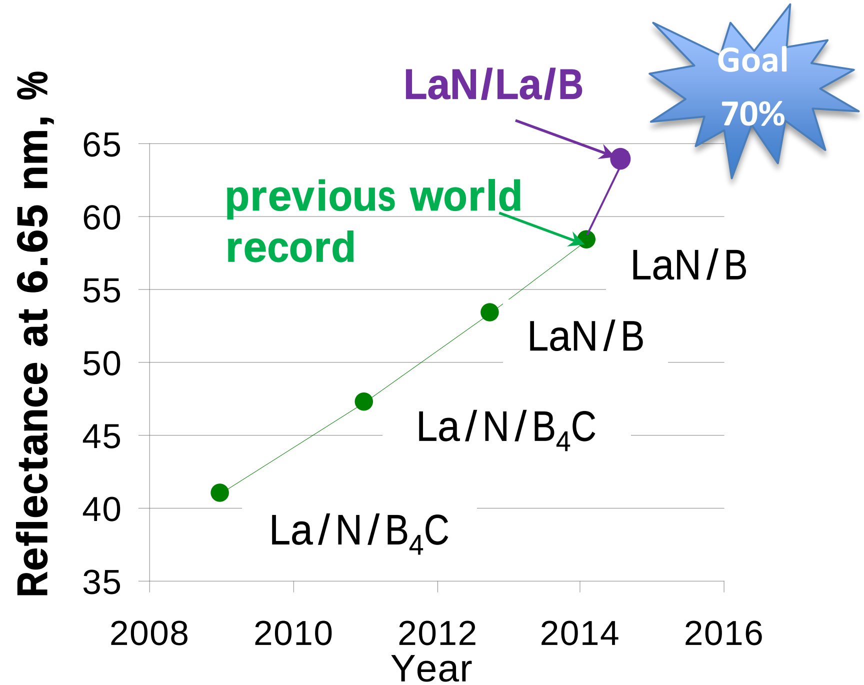
***[T. Tsarfati et al., Thin Solid Films 518(5), 1365 (2009)]*

=>Delayed nitridation should improve reflectance.

6.x nm world record

[D.S.Kuznetsov et al, Optics Letters, Vol. 40, No. 16 (2015)]

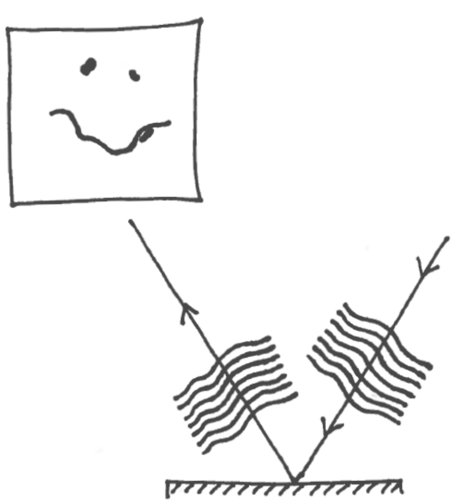


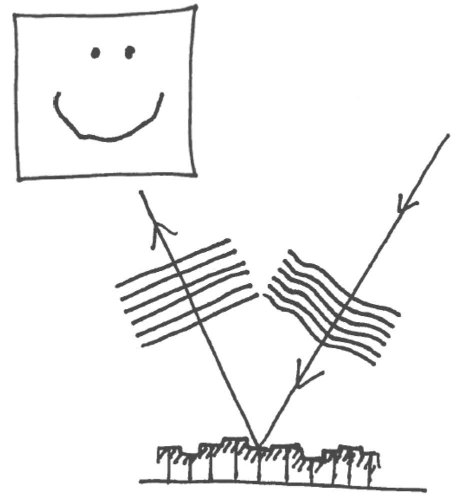


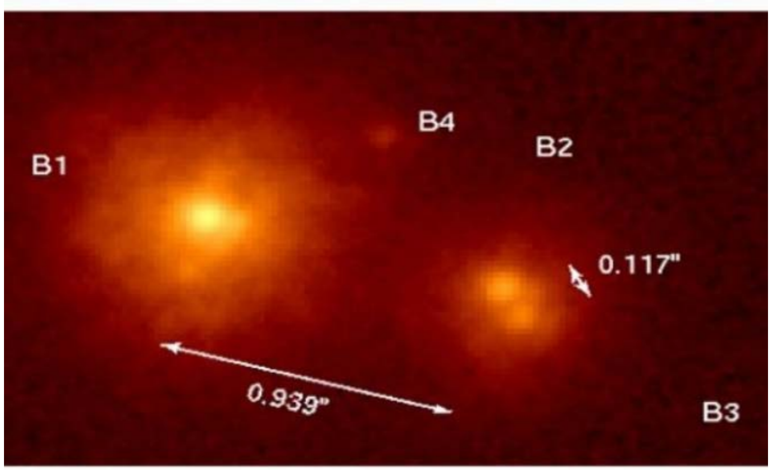
The gap to the application-desired performance significantly reduced.

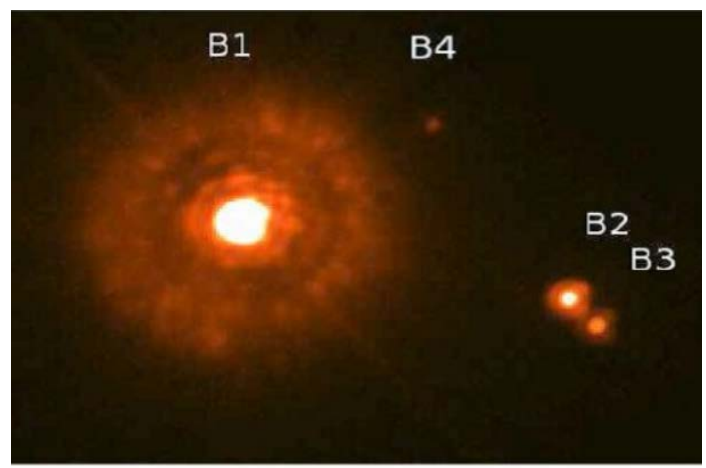
XUV FOM PANalytical ASML ZEISS MESA+ INSTITUTE FOR NANOTECHNOLOGY UNIVERSITY OF TWENTE.

Adaptive Optics: Wavefront correction



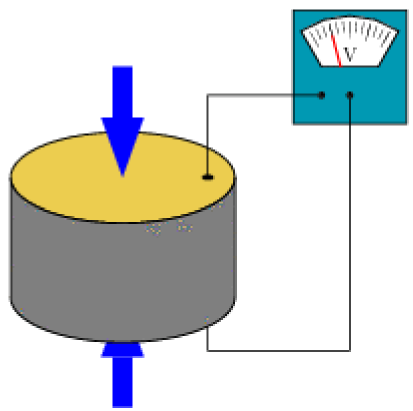




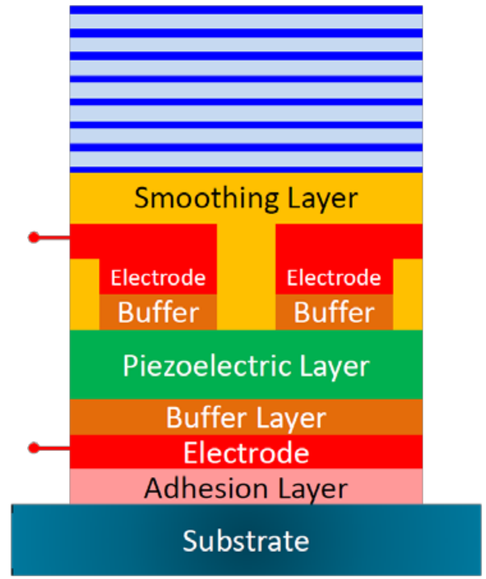


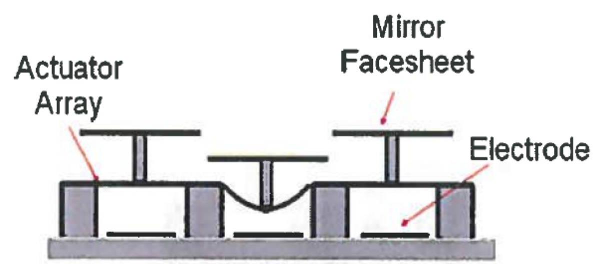
Theta1 Orionis B cluster. University of Arizona, Mirror Lab

Adaptive Optics for EUV-light



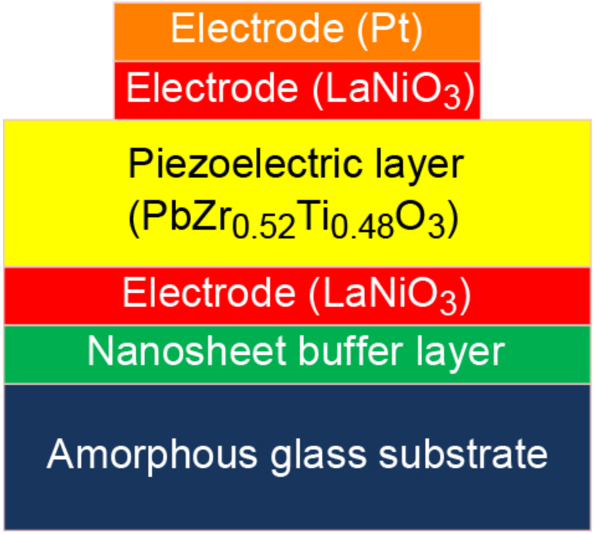
Piezo-electric effect

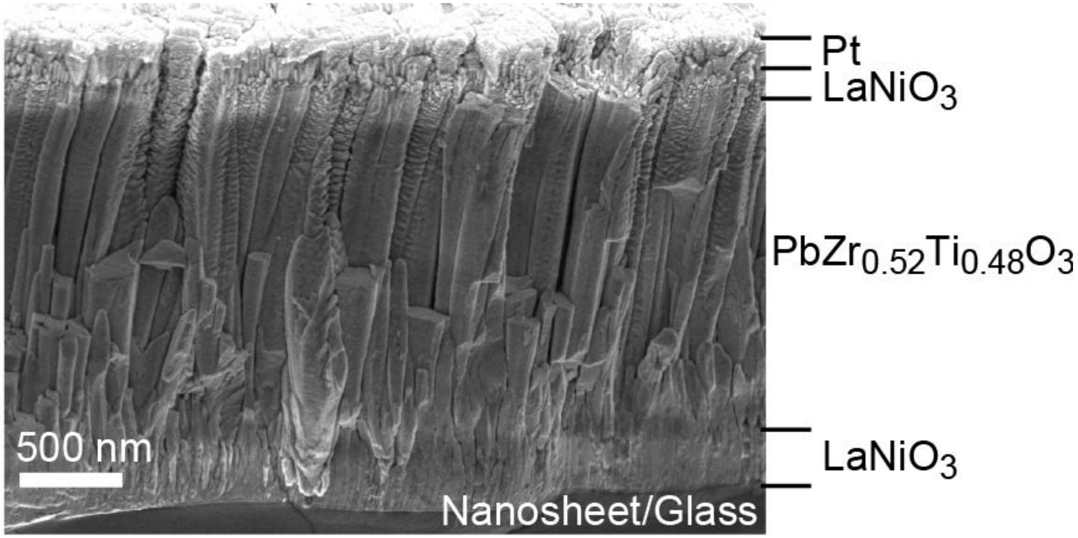




Spatial Light Modulator
(uncoupled control)

Piezo-electric effect: PZT thin films



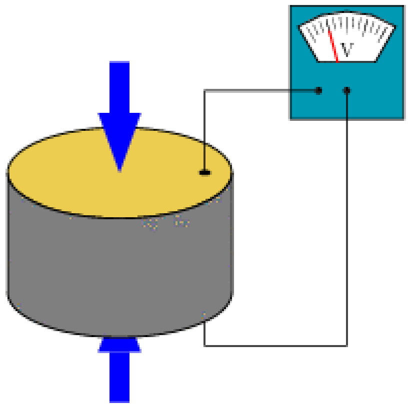


Pulsed laser deposition is used to grow PZT thin films

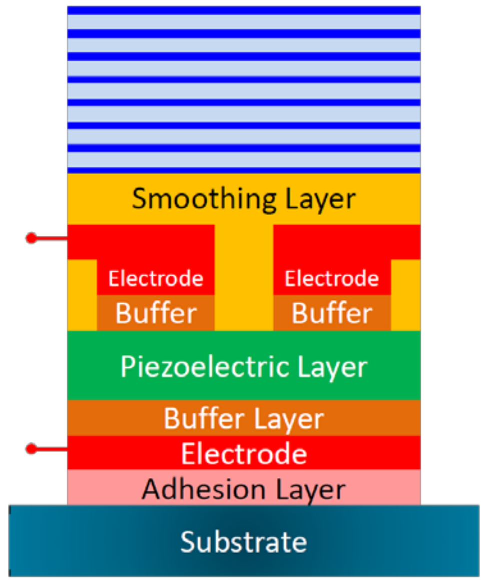
M. Bayraktar, F. Bijkerk et al., Optics Express, **22**, 30623 (2014)

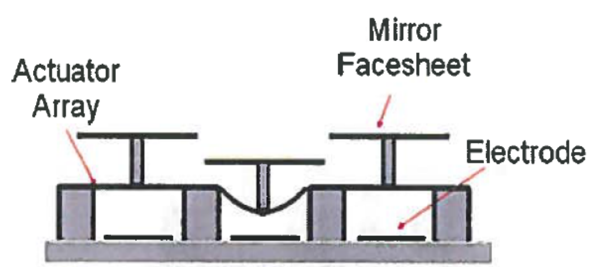
Piezo effect: Laser Doppler Vibrometer

Adaptive Optics for EUV-light

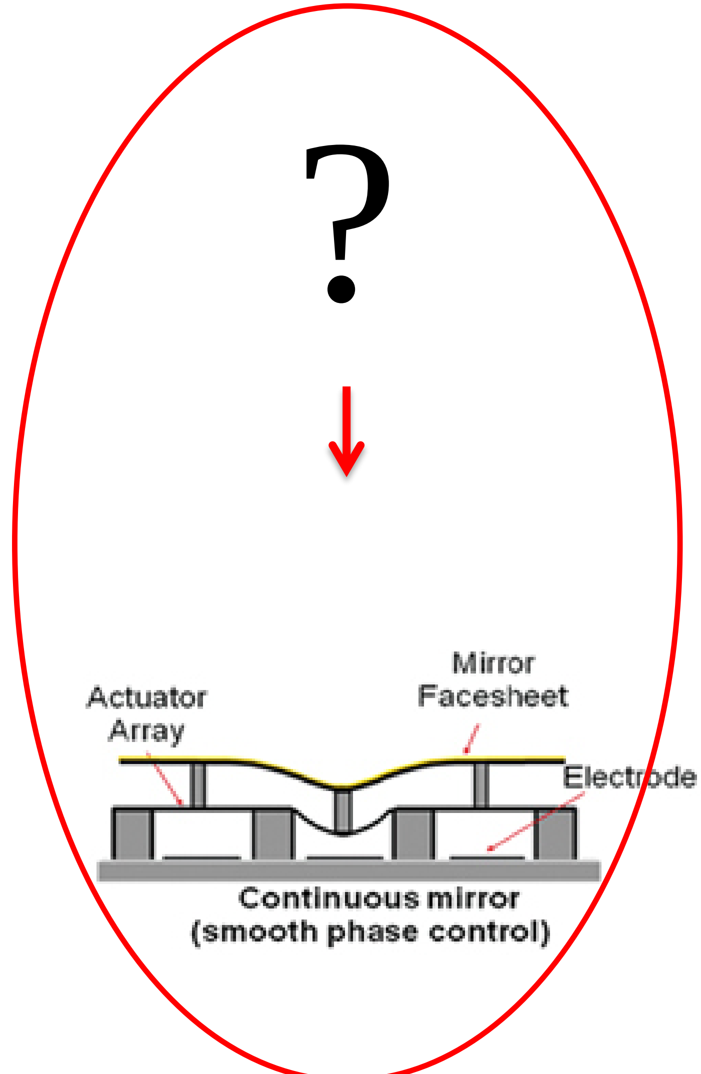


Piezo-electric effect

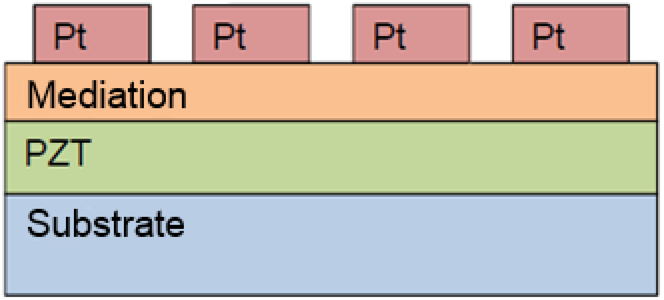


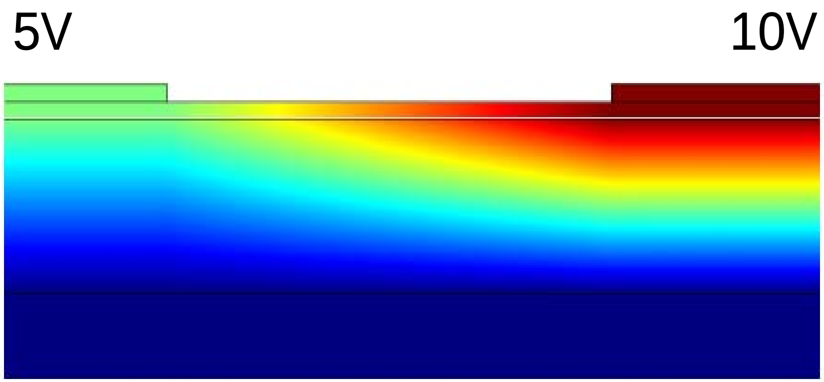


Spatial Light Modulator
(uncoupled control)

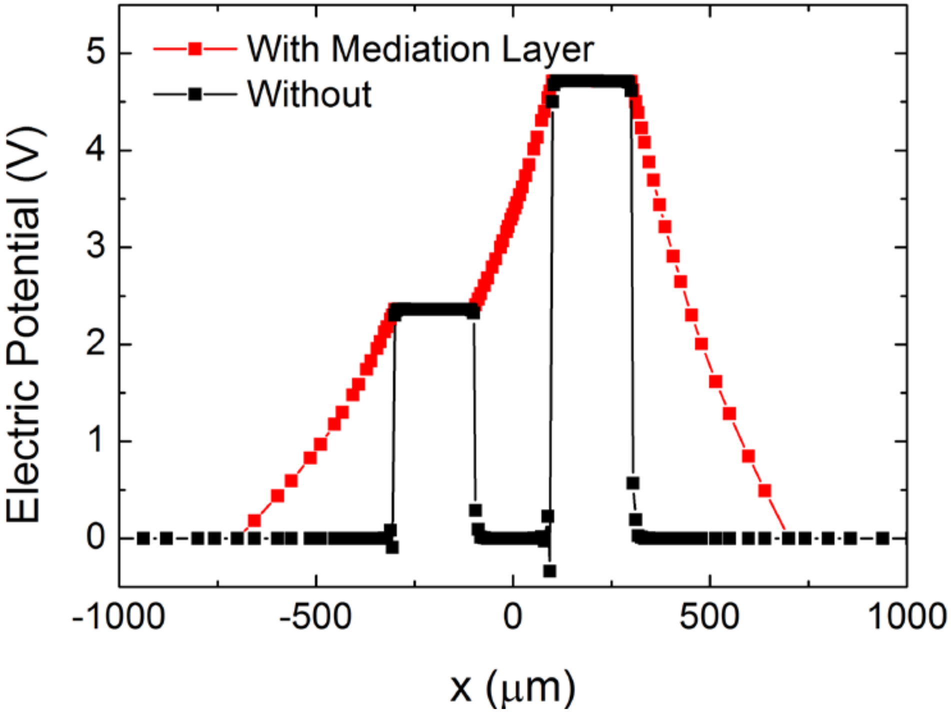


Piezoelectric mediation layer





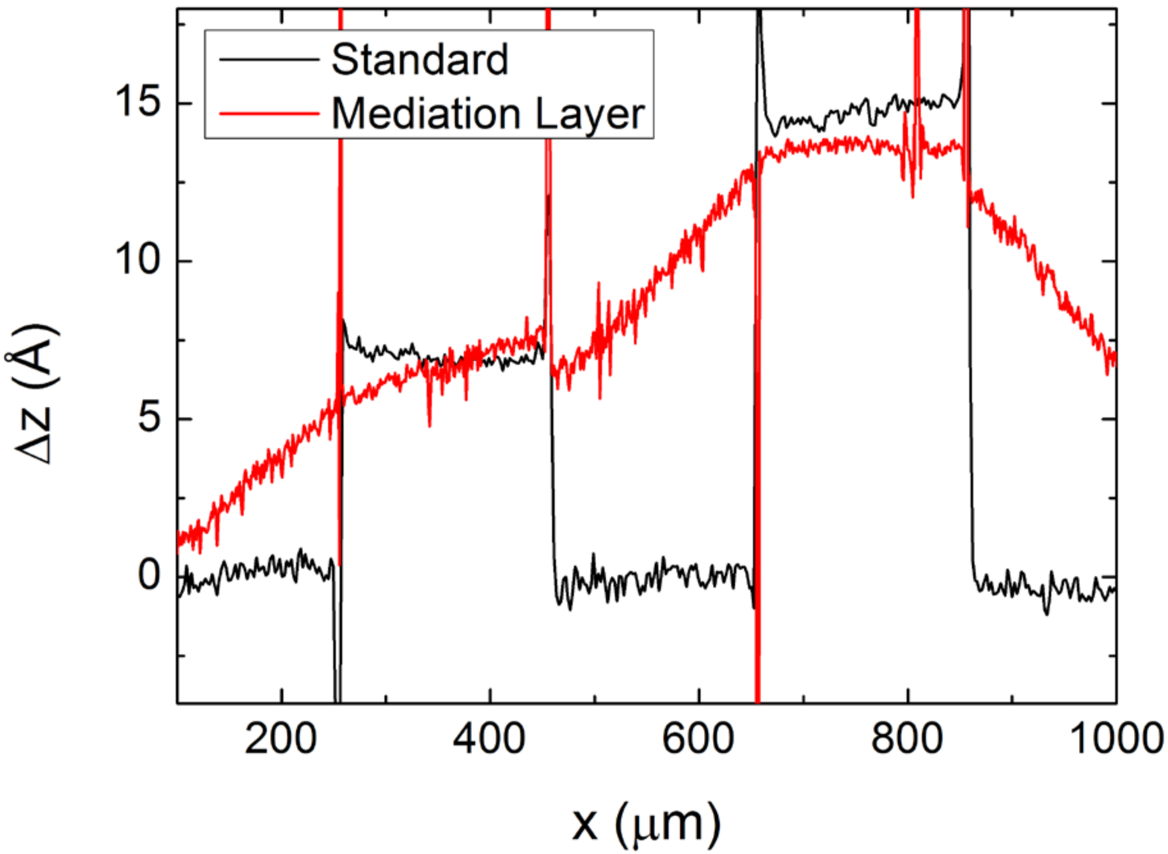
Cross section, colour scale is voltage



Modelling shows successful shaping of the voltage in the piezo layer

Modelling by Bram Krijnen, Demcon

Mediation layer in practice



White Light Interferometer: Mediation layer: smoothly transitioning surface height between electrodes

Summary

Recent developments EUV and B-EUV Multilayers

- **Accurate in-situ stress analysis**
  - Enables monitoring layer stress during all ML research processes
  - Stress during interface formation
  - Amorphous to crystalline phase transition in Mo
- **6.7 nm multilayers**
  - Time controlled nitridation of La prevents B-nitride formation, but a thin layer of La-boride is formed, which is less criotical for the reflectance
  - Peak reflectance La/LaN/B at normal incidence 64.3 %
- **Enabling steps towards adaptive optics for EUVL**
  - PZT piezo layers enable sub nm thickness variation control
  - Mediation layer: smooth transition between elements of adaptive optics

Thanks to the XUV Optics team

and the Metrology team at PTB Berlin

Thank you!